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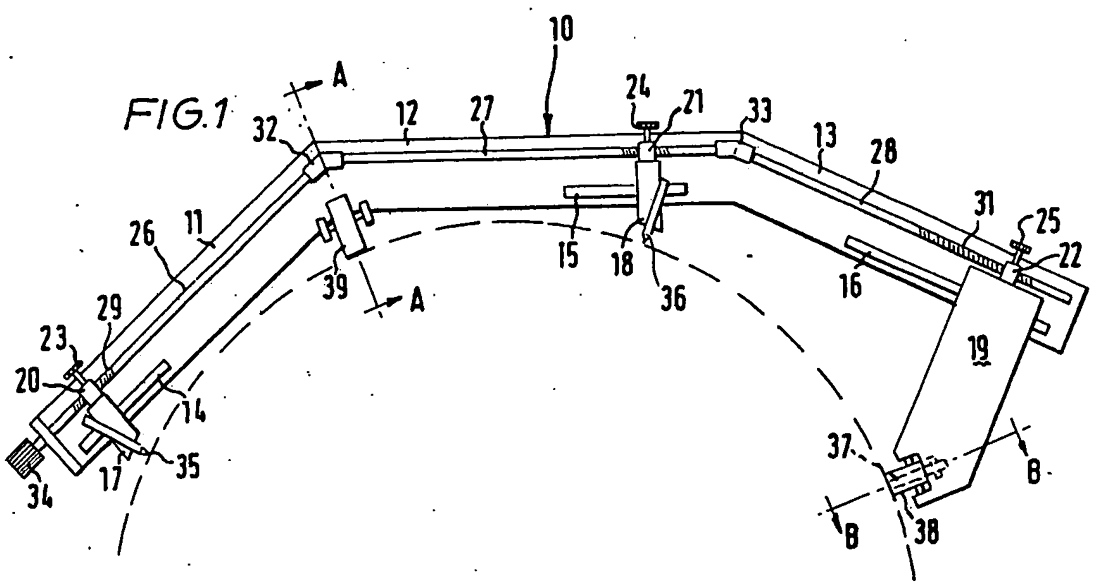
(54) Diametral variation determination for workpieces

(57) Apparatus for determining the variation in diameter along the length of a cylindrical workpiece, eg rolls for producing steel sheet, comprises a main body 10 having three slideways 14, 15 and 16 arranged at predetermined angles. Carriers 17, 18 and 19 are adjustably mounted on the three slideways respectively and each carrier has a linear transducer 35, 36 and 37 respectively mounted thereon. Carrier 19 supports a pair of wheels 38, and a further pair of wheels 39 is mounted equi-distant from transducers 35 and 36. In use, the apparatus is placed on a workpiece under test and adjusted until the outputs of all three transducers is substantially the same; thereafter the main body 10 is transversed on wheels 38 and 39 along the workpiece and the variations in the outputs of the three transducers is analysed to give an indication of the diametral variation of the workpiece, along the length thereof.

FIG.1



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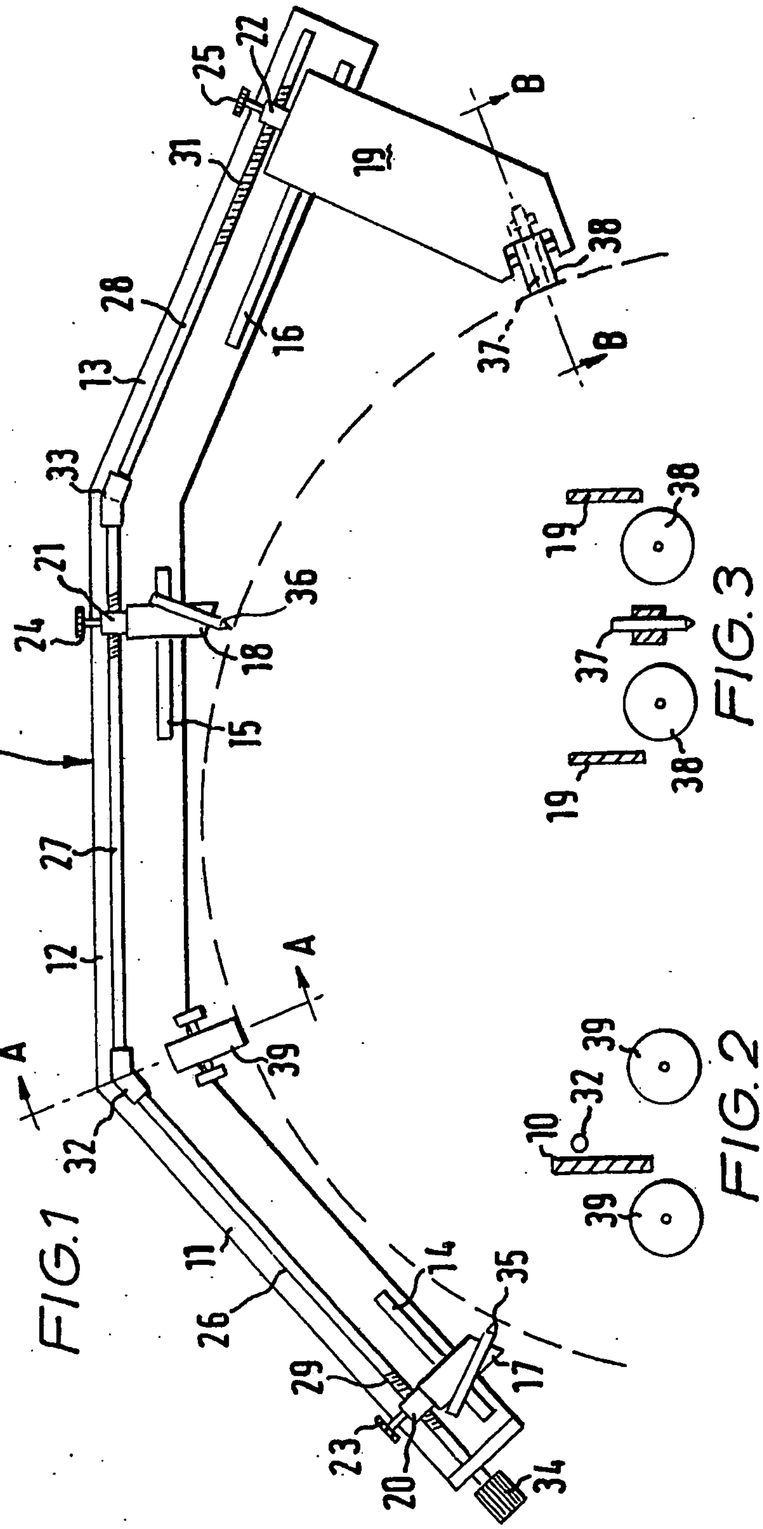

FIG.1

FIG.2

FIG.3

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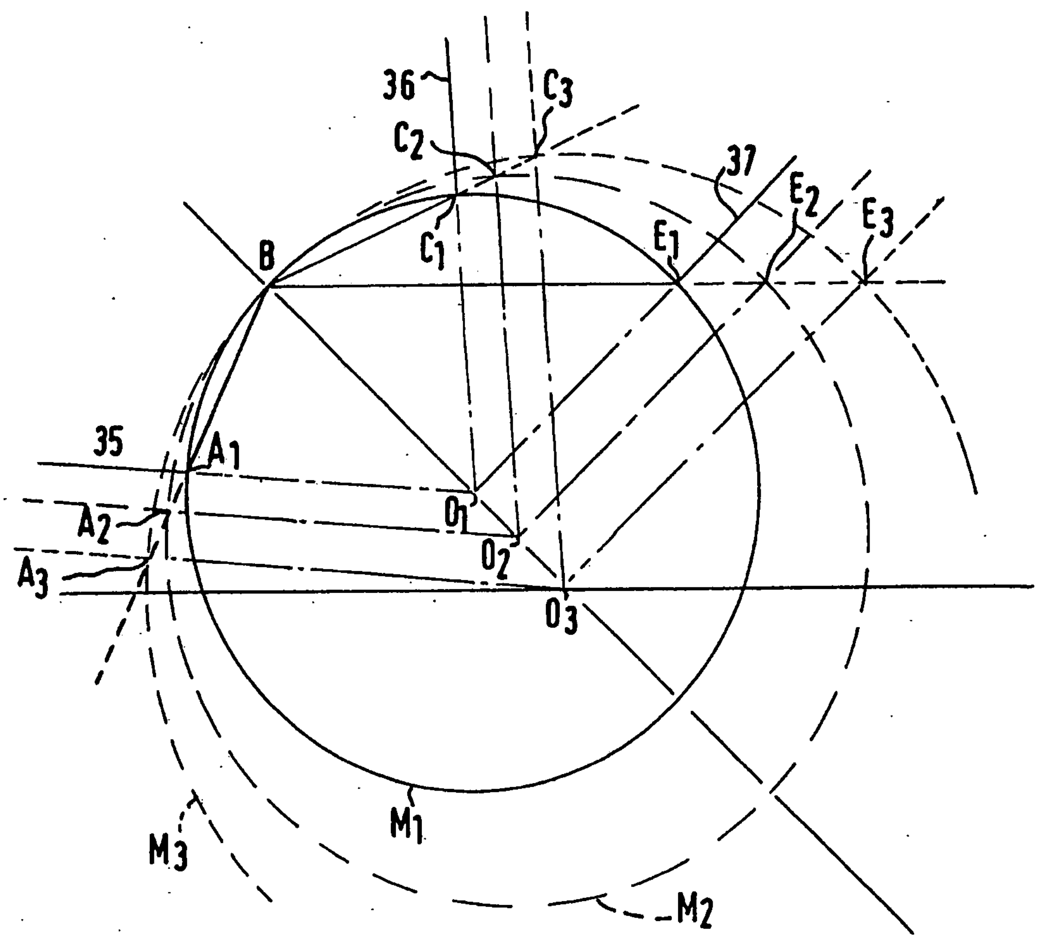

FIG. 4

SPECIFICATION

Diametral variation determination for workpieces

This invention relates to apparatus for determining variations in diameter along the length of a substantially cylindrical workpiece, and also to methods of determining variations in diameter of such a workpieces.

The manufacture of sheet-like products by rolling operations requires the use of rolls finished to standards of accuracy greater than that required for the sheet-like product itself. For example, the manufacture of relatively thin cold-rolled steel sheets is performed using cast iron or alloy steel rolls manufactured to very close tolerances, typically of the order of a few tens of microns. The production of rolls to such close tolerances causes extreme problems, not only in the manufacture of the rolls themselves, but also in checking the dimensional accuracy during the finishing stages of the manufacture.

There are two standard methods for the dimensional gauging of a roll under test. The first involves measurements made from a datum to points on the rolls. For example a straight edge may be mounted parallel to the roll axis such that the gap formed between the straight edge and the roll surface may indicate the variation in diameter of the roll, from one end to the other. The second involves the measurement of distances between points on the roll, using a gauging frame such as a micrometer to calliper the diameter at a series of locations along the roll axis.

The accuracy obtainable by the use of a reference edge is limited by the integrity and stability of that reference. Callipering methods rely on there being no significant error resulting from deformation of the callipers during measurement, and also on the callipers being maintained in the correct position and plane with respect to the surface being gauged. Whilst reasonable accuracies can be achieved with small workpieces, errors due to calliper deformation, misplacement and misalignment assume a greater significance as the size of the workpiece, and hence of the callipers employed, increases. These errors may be reduced by mounting the callipers on an independent support and guidance system, but on long workpieces such an arrangement can prove to be cumbersome and so difficult to use. An alternative approach is therefore to use the surface of the workpiece as part of the guidance system for the callipers, mounting the callipers on a wheeled carriage supported by and capable of traversing the roll from end to end. Such measuring systems need careful initial adjustment to ensure that the true diameter is callipered; the accuracy is often limited by the errors consequential upon the relative movement between the gauging system and the workpiece, which movement is produced by a variation in the parameter to be determined affecting the tracking of the carriage.

It is a principal object of the present invention to provide both apparatus and a method for determining the variation in diameter along the length of a substantially cylindrical workpiece, which apparatus and method significantly mitigate the disadvantages of the known systems, as described above.

Accordingly, one aspect of the present invention provides apparatus for determining variations in diameter along the length of a substantially cylindrical workpiece, comprising a carriage adapted partially to straddle the workpiece for traversing movement thereal-ong, the carriage having a primary mount to support the carriage on the workpiece and three arcuately-spaced displacement transducers for contacting the workpiece, each transducer producing an output so that the diametral variation may be determined therefrom as the carriage is traversed along the workpiece.

It will be appreciated that though in the present invention a carriage is supported by the workpiece for traversing the same, instead of the carriage supporting a gauging frame for determining the diameter of the workpiece, the carriage supports three arcuately-spaced displacement transducers, whereby the roll diameter variation may be determined from an analysis of the outputs of the three transducers, as the carriage is traversed. The apparatus of this invention thus relies on the geometric principle that there is only one diameter of circle that can be drawn through three defined points in space (that is, the tips of the transducers which contact the workpiece), and if the diameter of the workpiece varies as the carriage is traversed, so too will those points be displaced relatively, so permitting the diametral variation to be analysed from the transducer outputs.

In order to allow the apparatus to be used with a wide range of workpiece diameters, it is most preferred for there to be means adjustably mounting the transducers on the carriage which means is operable to cause the simultaneous adjustment of the arcuate spacing of all three transducers, whereby the apparatus may be adjusted for use with a workpiece the diameter of which falls within a predetermined adjustment range so that when adjusted to suit the nominal diameter of the workpiece under test, all three transducers are near the mid-point of their measuring range.

Each displacement transducer advantageously is a linear device and the adjustment means serves to maintain the line of action of all three transducers substantially radial to the workpiece for which the apparatus has been adjusted, simultaneous with the adjustment of the arcuate spacing adjustment. This may be

achieved by having each transducer mounted on a carrier slidably mounted on the carriage, the adjustment means including means to cause the simultaneous sliding movement of the carriers with respect to the carriage during adjustment of the apparatus.

Suitable configuration of the carriage together with the setting of the lines of sliding movement of the two outer carriers at appropriate respective obtuse angles to that of the intermediate carrier enables a simplified adjustment means to be obtained. For instance, the adjustment means may include a screw-threaded adjuster for each carrier, the screw-threaded adjusters being interconnected for simultaneous operation, for example by a manually-operable knob for use by an operator. A clamping arrangement should be provided for each carrier to eliminate possible errors resulting from relative movement between the parts of the apparatus, once adjusted for use with a particular workpiece.

By providing the primary mount between two of the displacement transducers, the apparatus may be made wholly self-supporting, without the need to provide additional supports for the apparatus. In this case, the adjustment means may serve to maintain the separation between one of said two displacement transducers and the primary mount equal to the separation between the other of said two transducers and the primary mount. The third displacement transducer may then be mounted on the carrier further from the primary mount than said other of the two transducers, the adjustment means causing the adjustment movement of the third transducer to be twice that of each of two said transducers.

The primary mount preferably comprises a wheeled support. The third transducer may have associated therewith at least one further wheel arranged to bear on the workpiece and serving as a secondary support for the carriage. Any eccentricity or other error in the primary or secondary support will be cancelled by virtue of the transducers producing corresponding output variations, so permitting only true diametral variations to be sensed.

Most preferably, each displacement transducer comprises a linear variable differential transformer. Such a transducer has an accuracy which is expressed as a fraction of its total measuring range. For the highest accuracy it is therefore desirable to utilise transducers with as short a range of travel as practicable. The configuration of the apparatus of the present invention allows the use of transducers with a measuring range of the same order of magnitude as the likely variation in the parameter being measured.

According to a second aspect of the present invention, there is provided a method of determining the variation in diameter of a substantially cylindrical workpiece using apparatus of this invention as defined above, which method comprises mounting the carriage on the workpiece, moving the carriage along the workpiece, and analysing the variations in the outputs of the transducers to obtain an indication of the diametral variation of the workpiece.

For the case of apparatus configured to permit adjustment to suit workpieces of different sizes, following the mounting of the carriage on the workpiece, the adjustment means should be adjusted until all three transducers provide respective reference outputs, conveniently with all the transducers yielding substantially the same output, and preferably with each transducer operating at or near its mid-range or zerooutput position, depending upon the type of transducer being employed. In this way, variations in diameter sensed as the carriage is traversed along the workpieces may be computed from the variations in the outputs of the transducers. The configuration of the carriage is such that the transducers themselves are located in the same plane, which is then maintained substantially perpendicular to the workpiece axis, the relative locations, orientations and loci of the transducers all being chosen to simplify the adjustment means itself.

One specific embodiment of apparatus of the invention will now be described in detail but by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of the embodiment of apparatus of this invention, mounted partially to straddling a roll under test, to determine the variation in diameter along the length of that roll;

Figure 2 is a diagrammatic section on line A-A marked on Figure 1;

Figure 3 is a diagrammatic section on line B-B marked on Figure 1; and

Figure 4 diagrammatically illustrates the geometry of the adjustment arrangement, enabling the transducers to remain radial to the workpiece under test, during adjustment.

The apparatus comprises a main body 10 having three distinct sections 11, 12 and 13 arranged at obtuse angles to one another and each having a linear slideway 14, 15 and 16 respectively. Slidably mounted on each slideway is a respective carrier 17, 18 and 19, each carrier having a respective screw-threaded nut 20, 21 and 22 as well as a respective clamping arrangement 23, 24 and 25. Adjuster rods 26, 27 and 28 are rotatably mounted on the sections 11, 12 and 13 respectively of the main body, each adjuster rod having a respective screw-threaded portion 29, 30 and 31 engaged with the respective nuts 20, 21 and 22 of the carriers 17, 18 and 19, respectively. Drive couplings 32 and 33, such as Hook couplings, are provided between the rods 26 and 27, and 27 and 28, rod 26 having at its outer end a knurled knob 34, whereby rotation of the knob 34 rotates

the rods 26, 27 and 28, so slidably moving the carriers 17, 18 and 19 along their respective slideways 14, 15 and 16.

Each carrier 17, 18 and 19 has mounted thereon at a predetermined angle a linear distance measuring transducer 35, 36 and 37, respectively. In addition to the transducer 37, the carrier 19 also is provided with a pair of wheels 38, the plane of which wheels contains the principal plane of the transducer 37.

Threaded portion 29 on rod 26, together with the corresponding internal thread in the nut 20, are left-handed, whereas the threaded portion 30 on rod 27 and the corresponding thread in nut 21 is right-handed, but all those threads are of the same pitch. Threaded portion 31 on rod 28 and nut 22 is also right-handed, but the pitch of that thread is twice that of the threaded portions 29 and 30.

At the junction between sections 11 and 12 of the main body 10, there is provided a further pair of support wheels 39, as shown in Figures 1 and 2.

The obtuse angles between the sections 11, 12 and 13, and hence also between the slideways 14, 15 and 16, the angles between the lines of action of the transducers 35, 36 and 37 and also the angle between the planes of the pairs of wheels 38 and 39 are all chosen such that when the tips of transducers simultaneously contact a cylindrical workpiece at approximately their mid-stroke positions, then the lines of action of those transducers will be substantially radial to that cylindrical workpiece. This is achieved by having the distance between the contact points of the wheels equal to $D/\sqrt{2}$ where D is the diameter of the cylindrical workpiece being measured, and by having the distance between the contact point of the measuring tip of transducer 35 and the contact points of wheels 38 as well as the distance between the contact points of those wheels and the contact point of the measuring tip of transducer 36 is equal to $D/2\sqrt{2}$.

The geometry of the apparatus shown in Figure 1 is illustrated in greater detail with reference to Figure 4, where circles M_1, M_2 and M_3 represent three rolls to be tested, these circles all touching at point B and having their respective centres O_1, O_2 and O_3 arranged in a line passing through point B. When the apparatus is adjusted to operate with a roll represented by circle M_1, the wheels 39 bear on the roll at B, and the contact points of transducers 35, 36 and 37 are shown at A_1, C_1 and E_1, on the circle M_1, with the lines of action of all three transducers passing through the centre O_1 of the circle M_1.

Adjustment of the apparatus to operate with a roll represented by circle M_2 is achieved by moving the three transducers with respect to point B, such that contact points A_2, C_2, E_2 are obtained on circle M_2, with the lines of action of all three transducers passing through the centre O_2 of circle M_2. Similarly, further adjustment to operate with a roll represented by circle M_3 is achieved by moving all three transducers with respect to point B such that contact points A_3, C_3, B_3 are obtained on circle M_3, with the lines of action of all three transducers passing throught the centre O_3 of circle M_3.

Appropriate selection of the angles between lines BA_1, BC_1 and BE_1 allow lines $A_1A_2A_3$, $C_1C_2C_3$ and $E_1E_2E_3$ to be linear with lines A_1O_1, A_2O_2 and A_3O_3 parallel, lines C_1O_1, C_2O_2 and C_3O_3 parallel and lines E_1O_1, E_2O_2, and E_3O_3 also parallel. Moreover, such selection of the angles further gives rise to distance A_1 A_3 being equal to C_1 C_3, and distance E_1E_3 being equal to twice distance A_1A_3. This selection permits the slideways 14, 15 and 16 to be linear with the transducers 35, 36 and 37 mounted with a fixed orientation with respect to their associated carriers, and also allows a simple drive arrangement for the carriers, with carrier 19 being driven at twice the rate of carriers 17 and 18.

Referring again to Figure 1, it will be appreciated that by releasing the clamping arrangements 23, 24 and 25 and turning the knob 34, the apparatus may be configured to suit any diameter cylindrical workpiece, within the range of adjustment allowed. The adjustment ensures that the lines of action of the transducers are always substantially radial and provided that the apparatus has correctly been set up, this adjustment will ensure that the transducers initially are at their mid-point, or to zero output position at the outset of a measuring operation on a cylindrical workpiece. This assists initial adjustment of the apparatus prior to a measurement operation; after the apparatus has been placed on a cylindrical workpiece to be tested, it is sufficient to effect adjustment of the knob 34 until the outputs from the transducers 35, 36 and 37 are all substantially equal.

It will be appreciated that the changes in diameter of a cylindrical workpiece under test along its length will be manifest from the changes in the outputs of the transducers 35, 36 and 37, as the main body 1 0 is moved along the length of the workpiece. By making use of the known angles between lines of action of the transducers, it is possible to determine the changes in the diameter being measured, in terms of the changes in the outputs of the transducers 35, 36 and 37, using a formula:

$$\delta d = a.\delta T1 + b.\delta T2 + c.\delta T3$$

where a, b and c are constants depending upon the particular geometry employed and $\delta T1$, $\delta T2$ and $\delta T3$ are the changes in the outputs of the three transducers 35, 36 and 37.

This formula allows evaluation of the

changes in diameter of the circumscribing circle passing through the points of contact of the measuring tips of the three transducers with the cylindrical workpiece under test. Provided that the main body 10 is maintained in a plane substantially perpendicular to the axis of the cylindrical workpiece, then small excursions of the main body 10 in this plane (for example due to any eccentricity in the wheels 38 or 39) have only a minor influence on the accuracy with which changes in the diameter of the cylindrical workpiece may be determined. This will hold good even though such excursions may produce comparatively large variations in the output of each transducer.

Though the embodiment of the invention as described above employs linear variable differential transformers as the transducers 35, 36 and 37, other forms of distance measurement transducer could be employed. For example, contacting or non-contacting transducers could be employed, including capacitive, inductive, resistive, pneumatic or optical transducers could be employed.

CLAIMS

1. Apparatus for determining variations in diameter along the length of a substantially cylindrical workpiece, comprising a carriage adapted partially to straddle the workpiece for traversing movement therealong, the carriage having a primary mount to support the carriage on the workpiece and three arcuately-spaced displacement transducers for contacting the workpiece, each transducer producing an output so that the diametral variation may be determined therefrom as the carriage is traversed along the workpiece.

2. Apparatus according to claim 1, wherein there is provided means adjustably mounting the transducers on the carriage which means is operable to cause the simultaneous adjustment of the arcuate spacing of all three transducers, whereby the apparatus may be adjusted for use with a workpiece the diameter of which falls within a predetermined adjustment range so as to have all three transducers in contact with the workpiece.

3. Apparatus according to claim 2, wherein each displacement transducer is a linear device and the adjustment means serves to maintain the line of action of all three transducers substantially radial to the workpiece for which the apparatus has been adjusted.

4. Apparatus according to claim 2 or claim 3, wherein each transducer is mounted on a carrier slidably mounted on the carriage, the adjustment means including means to cause the simultaneous sliding movement of the carriers with respect to the carriage during adjustment of the apparatus.

5. Apparatus according to claim 4, wherein the lines of sliding movement of the two outer carriers are at respective obtuse angles to that of the intermediate carrier.

6. Apparatus according to either claim 4 or claim 5, wherein the adjustment means includes screw-threaded adjusters for each carrier, the screw-threaded adjusters being interconnected for simultaneous operation.

7. Apparatus according to any of claims 2 to 6, wherein the primary mount is disposed between two of the displacement transducers.

8. Apparatus according to claim 7, wherein the adjustment means interconnects said two displacement transducers to maintain the separation between one of said two displacement transducers and the primary mount equal to the separation between the other of said two transducers and the primary mount.

9. Apparatus according to claim 8, wherein the third displacement transducer is mounted on the carriage further from the primary mount than said other of the two transducers, and the adjustment means causes the adjustment movement of the third transducer to be twice that of each of said two transducers.

10. Apparatus according to either claim 8 or claim 9, wherein said third transducer has associated therewith a wheel arranged to bear on the workpiece to assist supporting the carriage thereon.

11. Apparatus according to any of the preceding claims, wherein the primary reference mount comprises a wheeled support.

12. Apparatus according to any of the preceding claims, wherein each displacement transducer comprises a linear variable differential transformer, or a linear displacement transducer operating on one of an optical, capacitative, inductive, pneumatic, or resistive basis.

13. Apparatus according to claim 1 and substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

14. A method of determining the variation in diameter of a substantially cylindrical workpiece using apparatus according to any of the preceding claims, which method comprises mounting the carriage on the workpiece, moving the carrier along the workpiece, and analysing the variations in the outputs of the transducers to obtain an indication of the diametral variation of the workpiece.

15. A method according to claim 14 and in which apparatus according to any of claims 2 to 13 is employed, in which following the mounting of the carriage on the workpiece, the adjustment means is adjusted until all three transducers provide respective reference outputs.

16. A method according to claim 15, wherein the adjustment means is operated until all three transducers provide substantially the same output.

17. A method according to claim 13 and substantially as hereinbefore described.

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